PROJECT ID: eems045

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

Focused Validation of Select SMART Simulation Activities

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Vehicle Technologies Office - 2018 Annual Merit Review

June 19, 2018

Argonne NATIONAL LABORATORY | Idaho National Laboratory | BERKELEY LAB | OAK RIDGE National Laboratory | NREL NATIONAL RENEWABLE ENERGY LABORATORY

Overview

Timeline

Project start: 1 Oct 2017

Project end: 30 Sep 2018

Barriers

- Difficulty in sourcing accurate and traceable real-world data
- Accurately measuring transportation system impacts (data quality insights)
- Constant advances in technology drive unexpected CAV consequences

Budget

FY 2018: $165k (100% DOE)

Partners / Stakeholders

- DOE-SMART Consortium:
  - ANL
  - INL
  - LBNL
  - NREL
  - ORNL

Objective

<u>Objective: Support validation/data needs of SMART projects</u>

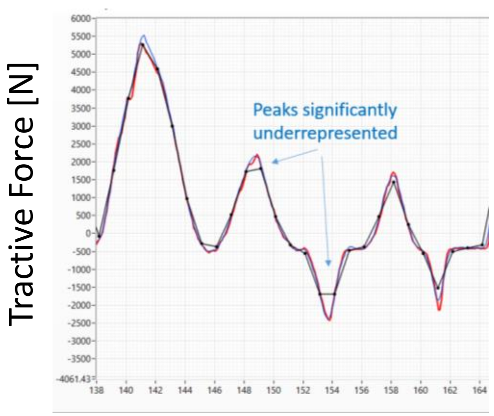
1. Validation/quantification of select vehicle-level CAV impacts
2. Investigation of data sampling/quality sensitivities relevant to SMART
3. Provide POC data collection strategies for requested data

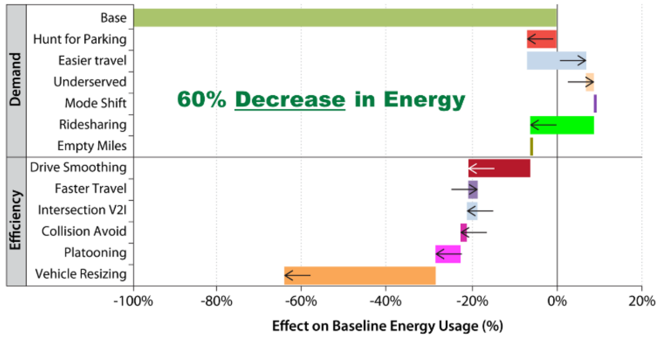
DOE Energy Efficient Mobility System (EEMS) Strategic Goals

STRATEGIC GOAL #1	STRATEGIC GOAL #2	STRATEGIC GOAL #3
Develop new tools, techniques, & core capabilities to understand & identify the most important levers to improve the energy productivity of future integrated mobility systems.	Identify & support early stage R&D to develop innovative technologies that enable energy efficient future mobility systems.	Share research insights, and coordinate and collaborate with stakeholders to support energy efficient local and regional transportation systems.

Project Approach

- Dynamometer based testing of A-to-B drive-cycles (CAV to non-CAV behaviors) with sufficient repeats to draw meaningful conclusions
  - Validate previous CAV impacts drawn from earlier literature and bounding reports
  - Aid in validation of specific SMART research projects (in collaboration with PIs)
- Utilize ANL's research fleet of instrumented CONV., HEV, PHEV & BEVs and historical data repository for evaluation of data quality/sampling sensitivities and possibilities for expanded data collection (per PI needs)





Source: Joint study by NREL, ANL, and ORNL
http://www.nrel.gov/docs/fy17osti/67216.pdf

Milestones

	Q1	Q2	Q3	Q4

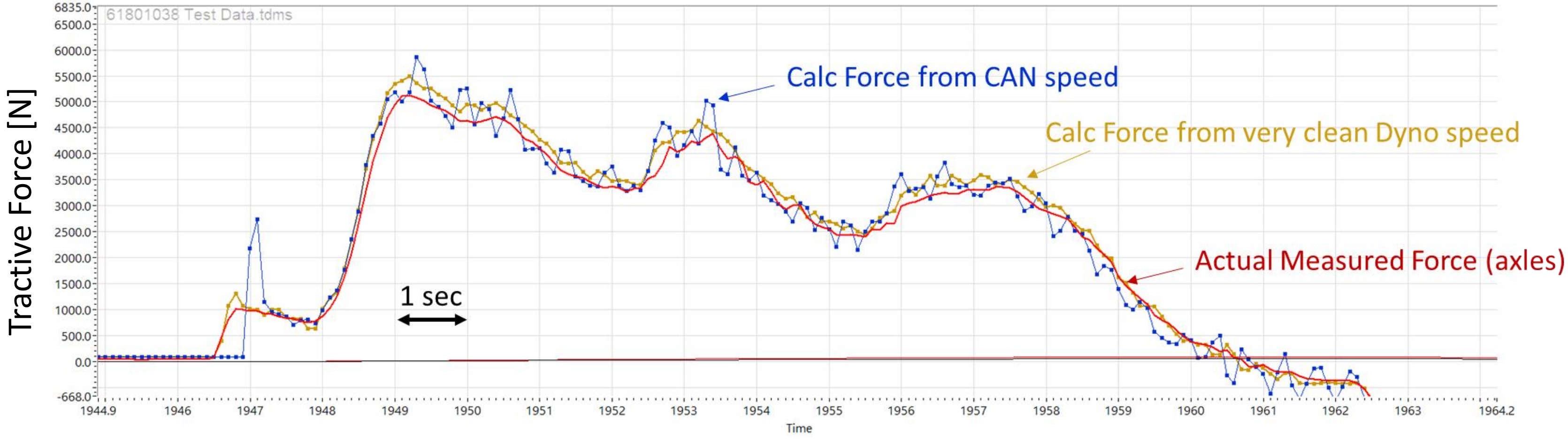
Data Quality and Sampling
- Tractive Force Sampling and Smoothing issues
- GPS (for vehicle loads), Battery Power, Fueling Sampling Rate and Quality Issues

Validation Testing
- Validation of Select External CAV References
- Coordination of Validation Tests with SMART PIs
- Collaborative Dynamometer Validation of SMART Results

PoC Instrumentation
- Compilation of Data Collection Needs
- PoC Roadway Behavior Data
- Occupancy Estimation
- On-Road Data Collection and Analysis

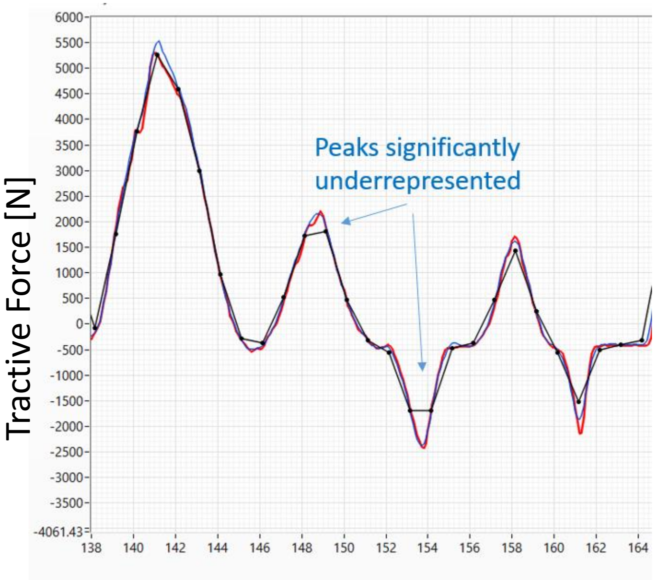
Data Quality – Tractive Force Sample Rate Matters

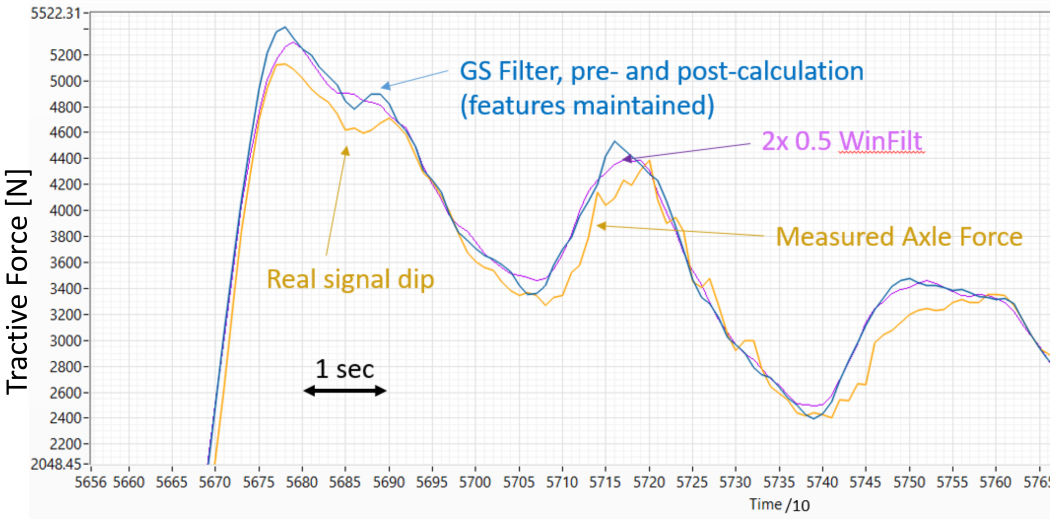
- Typical “detailed” data comes in 1Hz signal stream
- 1 Hz is adequate to define driving style, not adequate to derive a powertrain power trace
- What data needs are required?
- Vehicle network (CAN) data can be used to provide wheel power
- Research underway into **sample rate requirements** and **filtering strategy**



Data Quality – Sampling Recommendations (on-going)

- Using ANL road data, vehicle force can be calculated with clean CAN MPH data at 2-2.5 Hz
- Best results from 10 Hz data: Savitzky–Golay before and after force calculation (6 side pts, 2nd order)
- Current work on GPS data: Higher sample rate (~4Hz) needed
- GPS data requires additional smoothing and glitch detection

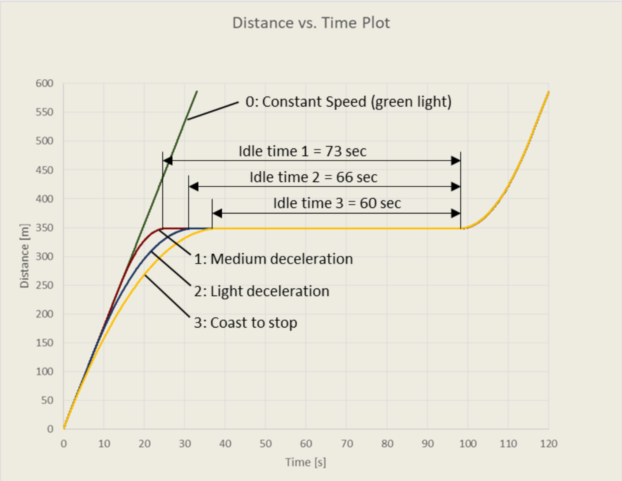


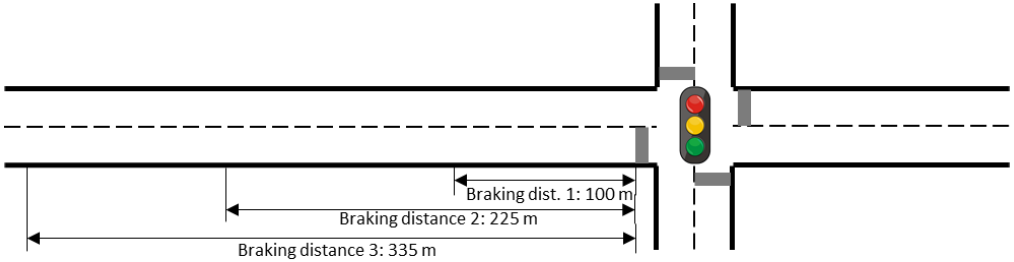


Highlighted Validation - Intersection Eco-Approach

<u>Based on simulation study in:</u>
Li, Meng, et al. "Traffic energy and emission reductions at signalized intersections: a study of the benefits of advanced driver information." International Journal of Intelligent Transportation Systems Research 7.1 (2009): 49-58.

- Compare fuel consumption for three different methods to approach an intersection with complete stop and idle, then constant acceleration up to cruise speed:
    1. Medium deceleration (similar to human driver)
    2. Light deceleration (w/ light braking force)
    3. Coast to stop (no use of brakes until the end)





Highlighted Validation - Intersection Eco-Approach (2)

- **F150 (No Idle Stop):** Fuel consumption benefits are greater than the benefits predicted in the reference study.
- **F150 (Idle Stop):** Fuel consumption benefits for are less than the benefits predicted in the reference study.

Fuel Consumption Comparison

Column1	Simulation Veh 1	Simulation Veh 2	Ford F150 (Start-Stop Disabled)	Ford F150 (Start-Stop Enabled)
Approach 1 vs Const. Speed	154.3%	166.3%	186.1%	116.4%
Approach 2 vs Const. Speed	132.0%	145.7%	159.3%	102.3%
Approach 3 vs Const. Speed	N/A	N/A	152.9%	101.4%
Approach 2 vs 1	-8.7%	-7.7%	-9.4%	-6.5%
Approach 3 vs 1	N/A	N/A	-11.6%	-7.0%

Stop for red light vs. pass on green light

Eco-approach vs. normal approach

Simulation results from literature

Dyno testing results from Argonne

- **Toyota Prius Prime (HEV):** Fuel consumption benefits much greater than the benefits predicted in the reference study.
- Fuel/energy consumption penalty for stopping at the intersection is less than 25% of the penalty incurred by the vehicles in the reference study.

	Simulation Veh 1	Simulation Veh 2	Prius Prime (HEV Mode)	Prius Prime (EV Mode)
Approach 1 vs Const. Speed	154.3%	166.3%	37.6%	40.6%
Approach 2 vs Const. Speed	132.0%	145.7%	17.6%	23.9%
Approach 3 vs Const. Speed	N/A	N/A	10.4%	16.6%
Approach 2 vs 1	-8.7%	-7.7%	-14.5%	-11.9%
Approach 3 vs 1	N/A	N/A	-19.8%	-17.1%

Stop for red light vs. pass on green light

Eco-approach vs. normal approach

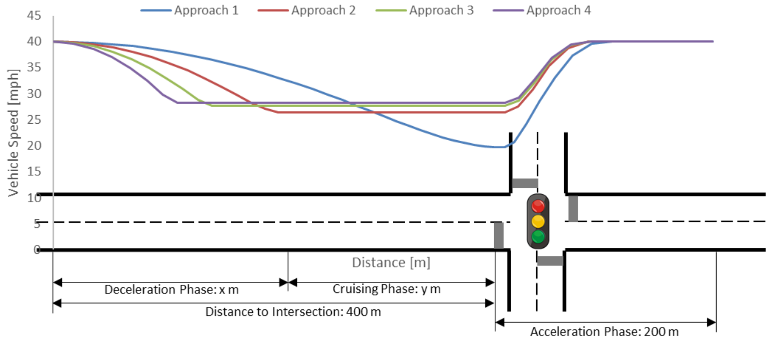
Simulation results from literature

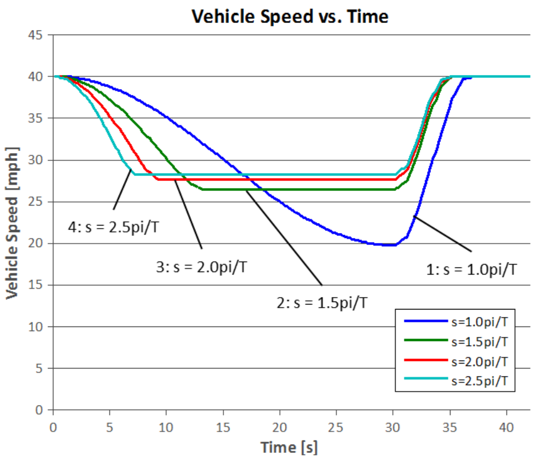
Dyno testing results from Argonne

Highlighted Validation - Eco-Approach and Launch

<u>Based on simulation study in:</u>
M. Barth, S. Mandava, K. Boriboonsomsin and H. Xia, "Dynamic ECO-driving for arterial corridors," 2011 IEEE Forum on Integrated and Sustainable Transportation Systems, Vienna, 2011, pp. 182-188. doi: 10.1109/FISTS.2011.5973594

- Compare fuel consumption for four different methods:
  1. Continuous deceleration all the way up to the intersection
  2. Light deceleration w/ 15 seconds constant speed cruise to intersection
  3. Medium deceleration w/ 20 seconds constant speed cruise to intersection
  4. Hard deceleration w/ 23 seconds constant speed cruise to intersection





Highlighted Validation - Eco-Approach and Launch (2)

Toyota Prius Prime (HEV and EV Modes)

- Sharper deceleration profiles have slightly lower consumption than the continuous deceleration profile due to the lower energy losses during the acceleration phase:
  - Regen energy from slowing down is roughly the same for all 4 four approaches.
  - Energy consumed during the cruise phase increases with increased cruise time
  - Energy consumed during acceleration decreases as the drive profile cruise speed increases
- There is very little difference in energy consumption for the three profiles with sharp braking and constant speed cruise.

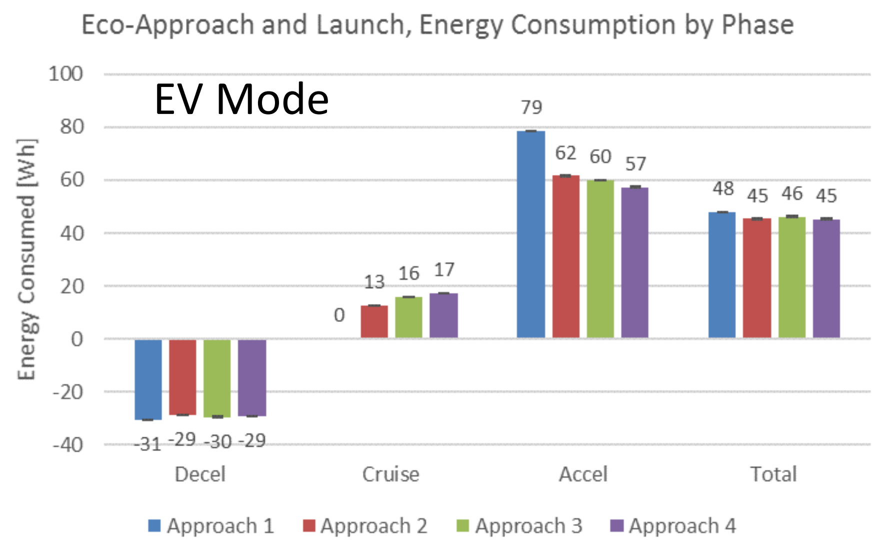
Eco-Approach and Launch Consumption Comparison

	Simulation Vehicle	Prius Prime (HEV Mode)	Prius Prime (EV Mode)
2 vs 1	-7.9%	-6.1%	-5.1%
3 vs 1	-9.3%	-6.8%	-5.3%
4 vs 1	-13.2%	-7.4%	-5.9%

Decel and cruise vs. continuous decel (1)

Simulation results from literature

Dyno testing results from Argonne



Highlighted Validation - Eco-Approach and Launch (3)

Ford F150:

- Fuel consumption benefits for eco-approach with sharper initial deceleration vs. light, continuous deceleration are significantly lower than the benefits predicted in the reference study.

- Unlike the reference, the highest fuel consumption benefit occurs for approach 3, not approach 4 with the sharpest braking.
  - The fuel consumption benefits for speed profiles 2 through 4 do not follow the same, increasing trend as in the simulation study by Barth et al.

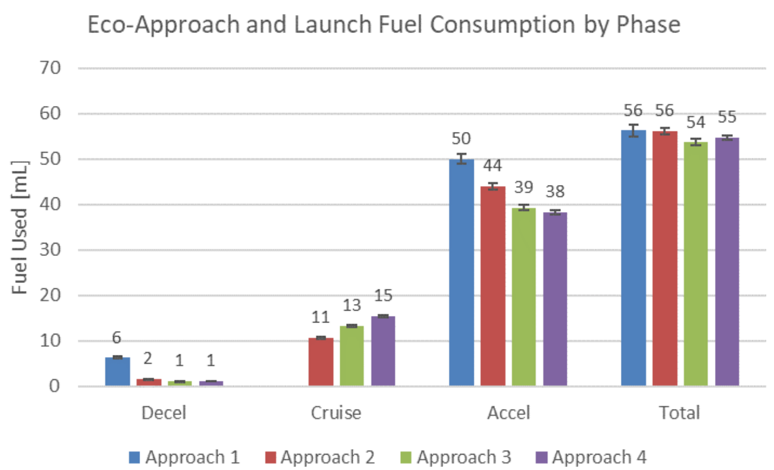
Eco-Approach and Launch: Fuel Consumption Comparison

	Simulation Vehicle	Ford F150
Approach 2 vs 1	-7.9%	-0.5%
Approach 3 vs 1	-9.3%	-5.0%
Approach 4 vs 1	-13.2%	-2.7%

Decel and cruise vs. continuous decel (1)

Simulation results from literature

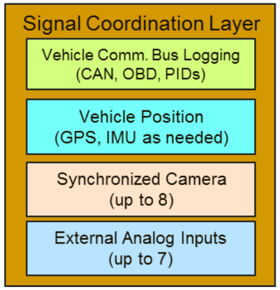
Dyno testing results from Argonne

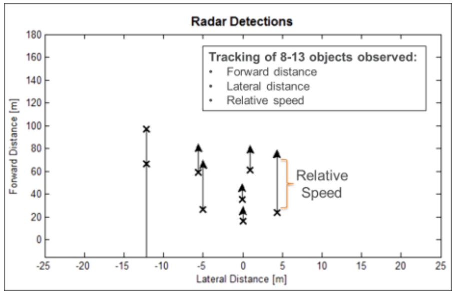


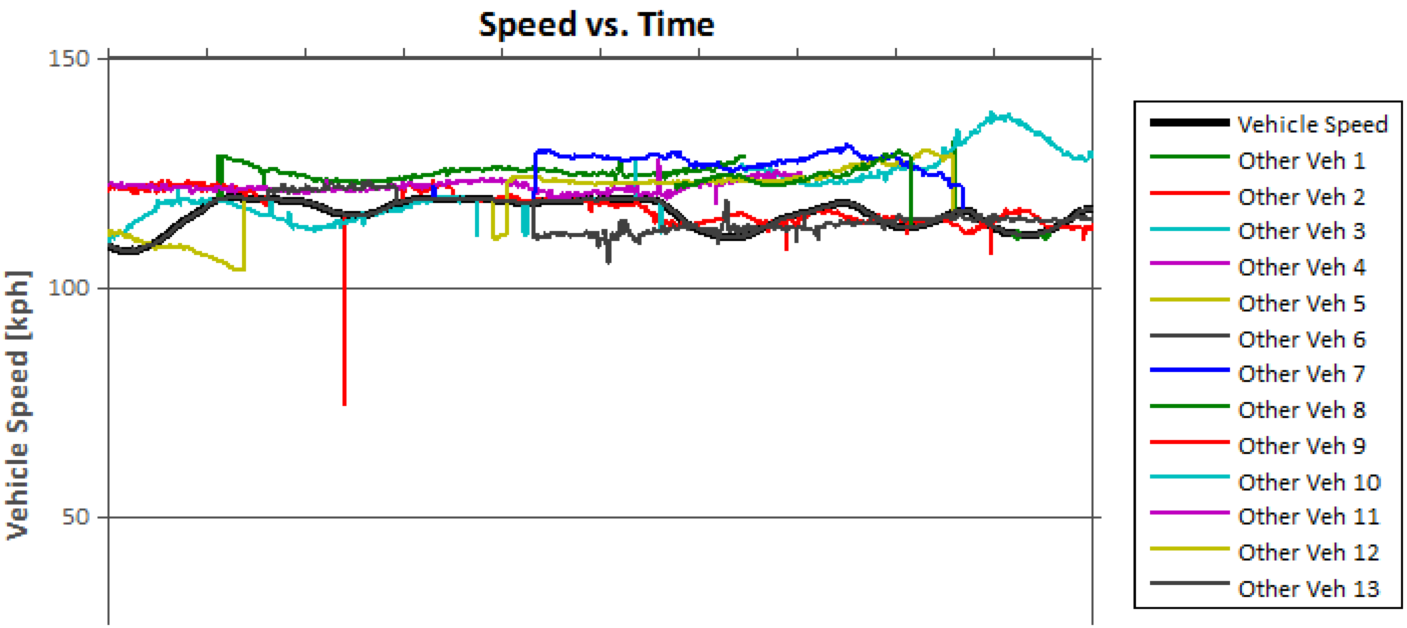
POC Data Collection – Collecting On-Road Information about Surrounding Driver Behavior

- Coordinated video and CAN logging from ACC system can offer insights into multiple vehicles

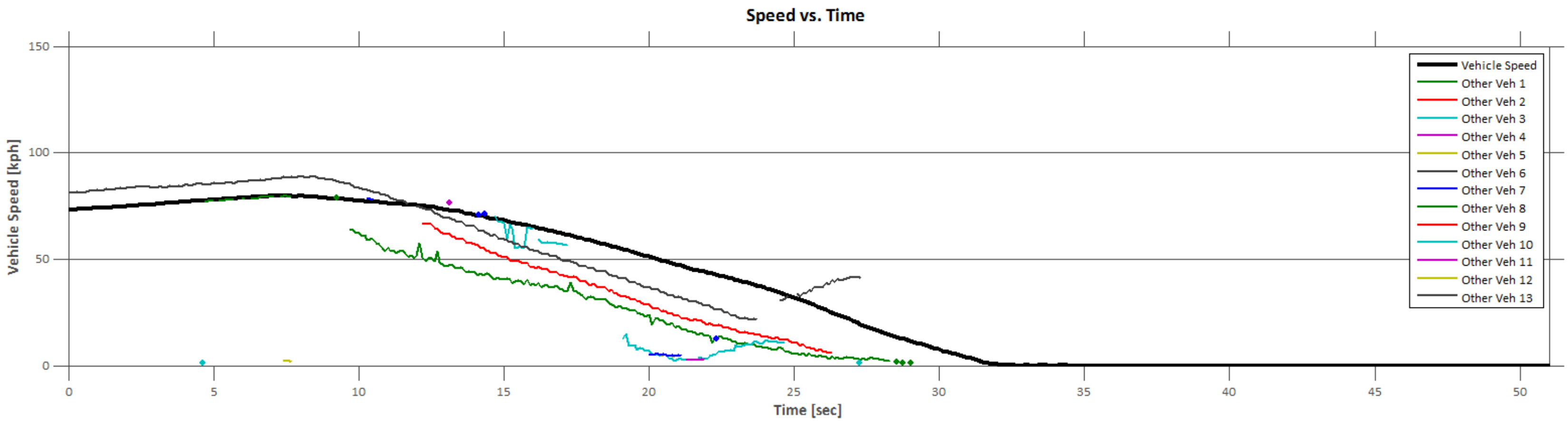
Vehicle-as-Sensor Hardware Overview







POC Data Collection – Traffic Light Approach Behavior for Multiple Vehicles



Partnerships / Collaborations

DOE SMART - National Laboratory Partners:

- Primary Participants: ORNL, ANL, INL, LBNL, NRELC
- Specific CAV Subprojects:
  - 2B – Aggregation Methods to Estimate National-Level Impacts of CAVs Scenarios
  - 2.1 - Multi-Scale, multi-scenario assessment of system optimization opportunities due to vehicle connectivity and automation (ST 1&2)
  - 3.2 - Experimental Evaluation of Eco-Driving Strategies and Cooperative ACC
- Coordination other DOE SMART Mobility pillars where/when applicable: AFI, CAVs, MDS, US

Proposed Future Work

Sampling Rate and Data Quality

- Comparison of fuel rate signal quality and availability across vehicles
- Sampling and collection needs for CAVs perception data (i.e. LIDAR traces, etc.)

Experimental Validation

- Improved coordination of validation efforts with SMART PIs –> Moving toward integrating/emulating scenarios used in analysis
- Highlighted emerging external references as incorporated by SMART projects
- On-road, on-track, and fleet validation and data collection support of select CAV technologies/approaches (alongside other SMART researchers)

Expanded Data Collection Needs

- Accessory power associated with the range of CAV capabilities is a large source of uncertainty (especially HAVs)
- Applicability of capabilities within other SMART pillars (i.e. Multi-Modal)

Summary

Relevance

- Quality validation and exploratory data is critical to SMART efforts

Approach

- Laboratory testing of CAV behaviors across a range of P-Trains
- Use existing, high-fidelity data repository as ground-truth to investigate relevant issues regarding sampling and data quality

Highlighted Accomplishments

- Tractive force sampling investigation
- Validation of select CAV references across a range of recent vehicle technologies and vehicles (HEVs, start-stop, pick-up)
- POC instrumentation can record on-road vehicle behaviors coordinated with system state information (ie traffic light)

Future/On-going work

- Continued support for SMART data and validation needs

Relevance

Approach

Accomplishments

Future work